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Ecological Aspect and Prospects of Sustainable Development of Regions

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Abstract

This study examines the relationship between rising average annual temperatures and disease incidence in Tashkent from 1991 to 2022, with a forecast extending to 2029. Using statistical time series analysis, the research employs the Spearman correlation coefficient and the autoregressive integrated moving average (ARIMA) model to predict morbidity trends. Findings reveal that Tashkent's temperate climate and agricultural development contribute to demographic growth, with the population increasing elevenfold from 1897 to 2023. However, rapid population growth, industrialisation, and urban expansion have intensified environmental pressures, increasing the burden on natural resources and infrastructure. Industrialisation, which accounts for almost 20% of Uzbekistan's production, has exacerbated air pollution and green space loss, further impacting public health. This, along with rising temperatures, affects public health, increasing the incidence of cardiovascular and respiratory diseases. A strong positive correlation (p = 0.761) was found between rising temperatures and the incidence of cardiovascular diseases per 100,000 people. In 2021, at an average annual temperature of 16.7°C, the incidence of cardiovascular diseases reached 8,730.2 cases per 100.000 population. Projections for 2023-2029 indicate a further increase in morbidity, underscoring the urgency for adaptive measures. The study recommends the implementation of adaptation measures focused on improving health services, preventive initiatives, and mitigating climate impacts. Further research should consider other factors, such as socio-economic status, quality of health care, and pollution levels, as well as examine the impact of climate on specific disease groups. The findings confirm the substantial impact of climate change on urban health, highlighting the importance of developing effective health policies.

Keywords

Climate change; Respiratory diseases; Cardiovascular diseases; Morbidity modelling; Temperature increases

Introduction

Climate change is increasingly causing humanitarian crises due to the rising frequency and intensity of extreme events such as forest fires, heatwaves, tropical storms, floods, and hurricanes. Scientific evidence suggests that approximately 3.6 billion people already live in regions that are extremely vulnerable to the effects of climate change. According to the World Health Organisation (2023a; 2023b), climate change is responsible for an additional 150,000 deaths each year as a result of malnutrition, malaria, diarrhoea, and heat stress. Projections suggest that between 2030 and 2050, these figures will not decrease, but rather rise to 250,000 deaths per year. A thorough analysis of the impact of climate change on disease risks at the local level was conducted by Patz and Olson (2006). The authors review various aspects, such as changes in the spread of infectious diseases, impacts on food security, water and air quality, and socio-economic factors. Emphasizing the connection between environmental change and human health, the authors highlight the urgent need to adapt health systems to the emerging challenges posed by climate change.

The projected climate change and uneven distribution of water resources in the region, together with their limited nature, will create additional challenges for the development of Uzbekistan's health system and economy. As one of the largest countries in Central Asia, Uzbekistan is predominantly located in an arid zone, and heavily relies on water resources from neighbouring countries to sustain its economic sectors. Internal water resources per person amount to only 531 m^3, which, combined with their uneven distribution and inefficient use, is a serious problem, especially for the agricultural sector (World Development Report, 2019). In addition, demographic forecasts indicate a substantial increase in the country's population, to 38.4 million by 2030 and to 44.4 million by the end of the century. These factors, closely linked to climate change, highlight the need for comprehensive scientific research to prevent possible crisis scenarios and prepare for future challenges.

Costello *et al.* (2009) highlight the critical need for health sectors to adapt to emerging environmental challenges and implement mechanisms to mitigate the negative impacts of climate change. Climate affects human health not only directly — through heat-related deaths and extreme weather events — but also indirectly (Konovalyuk *et al.*, 2023). As noted by Watts *et al.* (2021), indirect effects include water scarcity, an increase in the prevalence of infectious diseases, and an increase in mental and neurological disorders. Campbell-Lendrum *et al.* (2023) analyse three vital challenges that climate change poses to health systems:

- the impact of climate change on morbidity and mortality (analysing how temperature changes, weather extremes, and changes in ecosystems affect diseases such as malaria, water-borne diseases, and respiratory diseases);
- adaptation of health systems (considering adaptation strategies to improve the resilience of health systems to the effects of climate change);
- the need for an interdisciplinary approach (emphasising the importance of collaboration between scientists, policymakers, and the public to effectively respond to challenges that arise related to climate change).

The authors emphasise the need for active actions to reduce the negative effects of climate change on public health. Berry, Bowen and Kjellstrom (2010) suggest that climate change can negatively affect mental health through various channels, including physical stress from heat waves and economic pressures caused by the loss of resources from natural sources. Additionally, their latest study within the Intergovernmental Panel on Climate Change (IPCC) (2023) emphasises the need for a more in-depth analysis of local climate change and its impact on health at the level of individual regions such as Uzbekistan.

One of the most important climatic factors of influence is the increase in temperature fluctuations and the frequency of natural disasters (Shuvar *et al*., 2021; Borysiak *et al*., 2022). Gasparrini *et al.* (2017) made predictions about excess mortality due to rising temperatures, which is important for developing policies in the field of healthcare and social protection. Research on the impact of climate change on public health of the population of Tashkent remains limited, highlighting the need for further studies to develop effective adaptation measures. The purpose of this study is to examine the impact of climate change on the incidence of diseases in the city of Tashkent, especially cardiovascular and respiratory diseases. The objectives of the study were:

1. to analyse the dynamics of changes in the average annual temperature and ecological state of the city of Tashkent over a certain period;
2. to determine the correlation between the increase in the average annual temperature and the incidence of cardiovascular, respiratory, and oncological diseases among the population; and
3. to predict morbidity based on time series models to assess the potential impact of climate change on public health until 2029.

Materials and Methods

Study Area

The study was conducted from 2019 to 2023 based on the city of Tashkent, the capital of the Republic of Uzbekistan, considering the period from 1991 to 2022. Tashkent, as the largest and most populous city in Uzbekistan, serves as the country's political, economic, and cultural centre. Over the past few decades, the city has experienced rapid urbanization, industrial growth, and demographic expansion. Tashkent's location, with a climate conducive to agriculture and its proximity to the Chirchik River, supports a thriving agricultural sector. However, rapid industrialization, which contributes to nearly 20% of Uzbekistan's production, has led to air pollution, loss of green spaces, and environmental degradation, further exacerbating public health challenges. These factors, coupled with rising temperatures, have contributed to an increase in diseases such as cardiovascular and respiratory illnesses, making Tashkent a critical area for studying the impacts of climate change on urban health.

Data Collection and Analysis

The sample for this study was collected from both primary and secondary sources. This study utilized both primary and secondary data sources to examine the impact of climate change on public health in Tashkent. Secondary data were obtained from the following

institutions: Statistics Agency under the President of the Republic of Uzbekistan (2024) Ministry of Health of the Republic of Uzbekistan (2024), Ministry of Ecology, Environmental Protection, and Climate Change of the Republic of Uzbekistan (2024), Tourism Committee under the Ministry of Ecology (2024) and Ministry of Culture of the Republic of Uzbekistan (2024). These datasets included information on average annual temperatures, air pollution levels, and morbidity rates for cardiovascular, respiratory, and oncological diseases over a specified period.

To conduct a more detailed assessment of the correlation between temperature rise and morbidity rates in the city of Tashkent, the Spearman coefficient was applied (Formula 1). This statistical method measure the strength and direction of the relationship between two variables that do not have a normal distribution or when the relationship between them is nonlinear. It allows assessing whether there is a statistically substantial relationship between the increase in air temperature and the frequency of diseases, in particular, heat stroke, respiratory, and cardiovascular diseases. The formula used for the Spearman coefficient is as follows (1):

$$p = 1 - \frac{6\sum d^2}{n^3 - n} \quad (1)$$

Where: p – Spearman correlation coefficient, d – difference between the ranks of each pair of variables, n – number of observations. The correct placement of indicators is checked by calculating their total amount (Formula 2). If the sum of indicators (x and y) is equal to the checksum, this indicates that the indicators were assigned correctly (2):

$$\sum x_{ij} = \frac{(1+n)n}{2} \quad (2)$$

A critical value is determined to check the importance of the Spearman coefficient (Formula 3). In this case, the hypothesis that the correlation coefficient is zero is put forward and tested.

$$t_{\text{кр}} = t(\alpha, k)\sqrt{\frac{1 - \text{p}^2}{n-2}} \quad (3)$$

Where:
t (α, k) is the point of importance of a two-way critical region;
α – importance level (located according to the student's distribution table);
k = n-2 – the number of degrees of freedom (located according to the student's distribution table);
P – Spearman coefficient; n – the number of members (T Distribution Table, 2024).

The R software was used to predict future trends in environmental and health care, and the autoregressive integrated moving average (ARIMA) (0,1,0) model, which is a popular tool for analysing time series and allows predicting future values of variables

based on previous data. The components of the ARIMA model (0,1,0) mean that in this case, an integrated model is used without an autoregressive component or a moving average, but with one integration order, which means that the first data difference was applied to achieve stationarity. The use of ARIMA allowed making a forecast for the period from 2023 to 2029 for several variables: average air temperature, population morbidity, and mortality associated with heat stress. Data for building the model were obtained from climate observations conducted by the meteorological services of Uzbekistan and from statistical reports of the Ministry of Health of Uzbekistan on diseases caused by thermal conditions. This approach enables a data-driven prediction of climate-related health risks, supporting proactive adaptation measures. Data from the Ministry of Health of Uzbekistan (2024) were utilized to analyze morbidity trends in Tashkent's population, with a focus on diseases linked to rising air temperatures, including heat stroke, respiratory illnesses, and cardiovascular diseases. These health data were systematically compared with climate indicators, allowing for the identification of correlations between increasing temperatures and the incidence of temperature-related diseases.

Results

The city of Tashkent and its surrounding territories are located on the banks of the Chirchik River, which provides the region with a favourable climate for the development of agriculture. This creates optimal conditions for conducting agricultural activities, which in turn provide residents with ample opportunities for existence and well-being. The earliest recorded population data for Tashkent dates back to 1897, when the city had 154,400 inhabitants. Over the past century, the city's population has grown substantially, increasing elevenfold. Thus, in 1922, 260,000 people lived in Tashkent, and by 2023, this figure reached 2,956,400 people (Statistics Agency under the President of the Republic of Uzbekistan, 2024). This significant demographic expansion has had a direct impact on the city's ecological state, as population growth intensifies pressure on natural resources and infrastructure, contributing to environmental challenges.

The level of industrialisation, the volume of industrial production, and the structure of industrial sectors significantly influence the ecological state of Tashkent. The city contributes 19.7% of the Republic's industrial production, which indicates its important role in the economy of Uzbekistan (Statistics Agency under the President of the Republic of Uzbekistan, 2024). However, this concentration of industrial activity contributes to environmental pollution, which, in turn, affects the health of the population. Additionally, recent urban expansion has further affected the city's ecological balance, leading to increased air pollution and the loss of green spaces (Table 1).

Climate changes, particularly an increase in the average annual temperature, have a substantial impact on the ecological state of the city of Tashkent, which, in turn, leads to an increase in the burden on the population's morbidity. Climate change creates a complex noso-geographic and ecological situation in which numerous factors interact, affecting the health of residents (Skliar *et al.*, 2024; 2023). The increase in the average annual temperature is one of the most alarming phenomena, which directly affects the frequency of diseases, especially respiratory and cardiovascular diseases. Higher temperatures contribute to increased air pollution, as hot air traps pollutants such as

nitrogen and sulphur oxides, as well as fine dust particles (Yermukhanova *et al*., 2017). This creates conditions for the development of smog, which can cause or worsen various diseases, in particular, asthma, bronchitis, and other respiratory diseases.

Table 1: Dynamics of changes in the area and population of Tashkent

Years	*Area (km²)*	*By how many times the area increased (compared to 1922)*	*Population (thousand people)*	*How many times has the area increased (compared to 1922)*
1922	100	1.0	260	1.0
1951	117	1.2	626.2	2.4
1961	160	1.6	1037.1	3.9
1970	225	2.3	1384.5	5.3
1985	256	2.6	2035.9	7.8
2010	310	3.1	2107.8	8.1
2020	340	3.4	2571.7	9.9
2021	365	3.6	2694.4	10.4
2022	365	3.6	2862.4	11.0
2023	365	3.6	2956.4	11.4

Source: Statistics Agency under the President of the Republic of Uzbekistan (2024)

Reducing precipitation also plays an important role in shaping environmental conditions (Brovina and Sallaku, 2024). Dry periods lead to an increase in the concentration of dust and allergens in the air, which, in turn, can contribute to an increase in cases of allergic reactions and respiratory diseases (Lisiecka, 2024a; 2024b). Frequent dust storms typical of the region further increase the level of fine dust, which negatively affects the respiratory tract, especially in vulnerable populations such as children and the elderly. In addition, the accumulation of harmful emissions in the atmosphere is a serious threat to public health. Industrial emissions, road transport, and other sources of pollution contribute to the deterioration of air quality (World Health Organization, 2023b). Combined with rising temperatures, this can lead to an increase in cases of heart disease, as air pollution is a known risk factor for heart disease and strokes.

The combined effects of climate change and rising air pollution in Tashkent create conditions that contribute to the deterioration of public health. This connection underscores the urgent need for effective environmental strategies to improve air quality, reduce pollution, and enhance climate adaptation measures. Implementing these strategies is crucial to ensuring a healthier living environment for urban residents. Additionally, the incidence rate is affected by an increase in the concentration of allergens in the air, which increases due to rising temperatures and favourable conditions for the spread of various plants. This factor increases allergic reactions and increases the risk of asthma attacks in sensitive populations, especially in urbanised areas, as noted by the World Health Organisation (2023a). Air pollution caused by increased emissions from transport and industry also contributes to an increase in cases of asthma, chronic obstructive pulmonary disease, cardiovascular diseases, and even cancer (Tryhuba *et al*., 2022). Factors such as the ground-level ozone layer formed by solar radiation and high concentrations of carbon monoxide and nitrogen compounds further complicate breathing and negatively affect human health.

In addition to physical factors, the incidence rate in cities is also affected by social infrastructure. Lack of effective protection measures, insufficient access to quality health care, and low public awareness of the health risks associated with climate change worsen overall health (Prontenko *et al*., 2019; Zasorin *et al*., 2012). For example, Sharma *et al.* (2022) prove that in the absence of an adaptive infrastructure, climate change substantially increases the incidence of cardiovascular diseases. In turn, the European Environment Agency argues that factors such as limited access to health care and the vulnerability of the population to environmental risks are crucial in the process of assessing overall morbidity in cities with large populations.

Thus, the combination of physical, environmental, and social factors creates a complex set of impacts on the population's morbidity, which requires a systematic approach to risk analysis and the development of adaptation strategies. An in-depth analysis of the relationship between average annual temperature and the incidence of circulatory diseases helps to better understand how climate change affects public health and what aspects should be considered to reduce risks.

The Spearman correlation coefficient (Formula 1) was used to assess this relationship, which allows determining the level of dependence between two variables: average annual temperature and morbidity rates. The use of the Spearman coefficient is appropriate because the studied data may not correspond to the normal distribution, and the method allows the detection of even nonlinear relationships. The process of calculating the correlation coefficient involves pre-ordering the factor (temperature) and outcome (morbidity) traits (x, y) in ascending order, as shown in table 2. This ordering helps to avoid erroneous results and improves the accuracy of the analysis. If two or more values of one of the attributes match, they are assigned the same ranks by calculating the arithmetic mean of the positions. For example, table 2 defines positions 12, 13, 14, and 15 for the average annual temperature of 15.1°C in 1997, 1999, 2008, and 2009. These values were assigned an average rank of 13.5 (calculated as (12+13+14+15) / 4) to achieve the correctness of the analysis. The same procedure applies to temperatures of 7.5°C (for the years 1998 and 2012), 27.5°C (for 2004 and 2015), 5°C (for 1991, 1992, 2014), and 30.5°C (for 2016 and 2022).

Table 2: Table for calculating the Spearman coefficient (based on data from the city of Tashkent)

No.	*Year*	*Average annual temperature, °C (x)*	*Morbidity of the population with diseases of the circulatory system (y)**	*Position X (dx)*	*Position Y (dy)*	$d^2=(dx-dy)^2$
1	1991	14.4	647.9	5	2	9
2	1992	14.4	662.4	5	3	4
3	1993	13.4	614.4	1	1	0
4	1994	14.3	684.8	3	4	1
5	1995	15	902.3	11	6	25
6	1996	14	803.8	2	5	9
7	1997	15.1	1079.4	13.5	8	30.25
8	1998	14.6	933.4	7.5	7	0.25

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No.	*Year*	*Average annual temperature, °C (x)*	*Morbidity of the population with diseases of the circulatory system (y)**	*Position X (dx)*	*Position Y (dy)*	$d^2=(dx-dy)^2$
9	1999	15.1	1098.4	13.5	9	20.25
10	2000	15.4	1422.4	20	12	64
11	2001	15.7	1502.5	23	14	81
12	2002	15.2	1460.8	17	13	16
13	2003	14.8	1593.1	9	15	36
14	2004	15.9	1768.7	27.5	16	132.25
15	2005	15.3	1897.3	19	18	1
16	2006	15.5	2062.7	21	22	1
17	2007	15.2	1940.7	17	19	4
18	2008	15.1	1979.0	13.5	20	42.25
19	2009	15.1	2025.9	13.5	21	56.25
20	2010	15.8	1885.3	25	17	64
21	2011	14.9	1362.9	10	11	1
22	2012	14.6	1299.2	7.5	10	6.25
23	2013	15.8	2398.3	25	25	0
24	2014	14.4	2785.6	5	27	484
25	2015	15.9	3044.9	27.5	28	0.25
26	2016	16.5	3104.4	30.5	29	2.25
27	2017	15.6	2567.6	22	26	16
28	2018	15.8	2133.3	25	23	4
29	2019	16.4	2225.5	29	24	25
30	2020	15.2	5027.0	17	30	169
31	2021	16.7	8730.2	32	32	0
32	2022	16.5	7461.6	30.5	31	0.25
				528	528	$\sum d^2 =$ 1304.5.

Note: * - incidence of circulatory system diseases per 100,000 population.
Source: Urban and Rural Population by Region (2024)

The correctness of placing indicators in the rating scale is checked by calculating their total amount (Formula 2). If the sum of the rank indicators (x and y) coincides with the control value of the sum (calculated for the corresponding data set), this means that the indicators are assigned correctly and that there are no errors in their ordering. This check helps to avoid errors in the subsequent calculation of the Spearman correlation coefficient, ensuring the accuracy of the results:

$$\sum x_{ij} = \frac{(1+32)32}{2} = 528.$$

Then, for each pair of values, the difference between the indicators is determined ($d^2 = (d_x - d_y)2$) for each observation. Each difference is squared, which avoids negative values and increases the impact of large deviations. The total sum of squared differences

$\sum d^2$ in this example, it is 1304.5. This value is an important parameter for calculating the Spearman coefficient by substituting the identified values in Formula 1.

$$p = 1 - \frac{6*1304.5}{32^3-32} = 1 - \frac{7827}{32736} = 1 - 0.239 = 0.761.$$

Here, t (α, k) is the critical point of a two-way critical region, the importance level (α) and the number of degrees of freedom (k=n-2) are determined from the student's distribution table: t(α, k)=(0.1/2;30)=1.70; p – Spearman's coefficient; n – the number of terms (T Distribution Table, 2024). The critical correlation value, $t_{kp,}$ is calculated to estimate the importance of the Spearman coefficient (Formula 3). The test hypothesis is that the correlation coefficient is zero, i.e., there is no linear relationship between the variables.

$$t_{\text{кр}} = 1.7\sqrt{\frac{1-0.761^2}{32-2}} = 1.7\sqrt{\frac{1-0,579}{30}} = 1.7\sqrt{\frac{0.421}{30}} = 0.2.$$

If $H_0: p = 0$, then there is no linear relationship between variables, if $H_0: p \neq 0$, then there is a linear relationship between the variables, and the correlation coefficient is recognised as substantial. In our case, since p(0.761) > t_{kp}(0.2), the obtained correlation coefficient indicates a relationship between rising temperatures and the incidence of circulatory system diseases. This finding serves as a basis for further research and the development of preventive measures for the population. The Cheddock scale was used for a qualitative assessment of the density of the relationship between the factor and the result (Table 3).

Table 3: Cheddock Scale

Quantitative measure of interconnection	*Qualitative measure of interconnection*
0.1-0.3	Weak
0.3-0.5	Moderately weak
0.5-0.7	Perceptible
0.7-0.9	Strong
0.9-0.99	Very strong

Source: Sharma *et al.* (2022).

In this case, the coefficient value ranges from -1 to +1. If the coefficient (p) is in the range of 0;+1, then the relationship is rectilinear; if in the range of 0;-1, the Inverse is linear, and if the coefficient is zero, this indicates that there is no relationship between the features. The analysis shows that the relationship (p = 0.761) between the average annual temperature of the city (x) and cardiovascular diseases of the population (y) is strong and direct. A thorough review of the dynamics of morbidity of the population of Tashkent for the period 1991 to 2022 is presented in table 4 for several key indicators: diseases of the cardiovascular system, respiratory organs, malignant neoplasms, and the general morbidity of the population. These data indicate a clear relationship between an increase in the average annual temperature and an increase in the number of diseases in the population.

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Table 4: Morbidity of the population of Tashkent in the period 1991-2022

Years	*Morbidity of the population with diseases of the cardiovascular system*	*Respiratory diseases*	*Malignant neoplasms*	*General morbidity of the population*	*Average annual temperature, °C*
1991	647.9	27615.9	190.1	47899.3	14.4
1992	662.4	28080.2	192.5	48124.1	14.4
1993	614.4	25774.2	193.2	48681.6	13.4
1994	684.8	26443.7	190.1	49369.3	14.3
1995	902.3	24543.9	159.8	49523.3	15.0
1996	803.8	16110.5	104.7	50533.8	14.0
1997	1079.4	16400.9	114.4	51232.9	15.1
1998	933.4	17507.3	103.4	52233.0	14.6
1999	1098.4	17236.6	119.9	53892.1	15.1
2000	1422.4	19930.3	123.1	56532.3	15.4
2001	1502.5	19466.2	124.1	57581.0	15.7
2002	1460.8	19593.1	120.5	59672.3	15.2
2003	1593.1	18945.4	117.9	61335.0	14.8
2004	1768.7	17695.5	115.5	64888.8	15.9
2005	1897.3	17398.1	109.8	63944.6	15.3
2006	2062.7	17676.1	124.1	64460.4	15.5
2007	1940.7	18732.4	138.4	68381.6	15.2
2008	1979.0	18921.6	131.3	68477.4	15.1
2009	2025.9	19198.5	125.5	69527.6	15.1
2010	1885.3	17689.3	125.2	68477.4	15.8
2011	1362.9	18370.4	136.2	65784.4	14.9
2012	1299.2	18916.9	133.5	63477.6	14.6
2013	2398.3	28703.1	136.7	78954.1	15.8
2014	2785.6	29489.7	142.4	84476.9	14.4
2015	3044.9	30326.4	147.1	94014.3	15.9
2016	3104.4	34560.5	138.6	98322.0	16.5
2017	2567.6	39281.3	166.7	106842.5	15.6
2018	2133.3	35322.7	176.4	99709.5	15.8
2019	2225.5	32949.5	170.3	94789.8	16.4
2020	5027.0	27496.0	134.1	123115.7	15.2
2021	8730.2	25490.7	158.3	139521.0	16.7
2022	7461.6	27914.3	148.1	146833.6	16.5

Rates of cardiovascular diseases show a substantial increase, especially after 2000 when the average annual temperature rose to 15.4°C. For example, in 2016, when the average annual temperature reached 16.5°C, the incidence was 3,104.4 cases per 100,000 population. In 2021, when the temperature rose to 16.7°C, the number of cases reached a record 8,730.2. Respiratory diseases also tended to increase over the years. The highest rates were recorded in 2017 – 39,281.3 cases, which coincides with an increase in the average annual temperature to 15.6°C. Rising temperatures contribute to more frequent respiratory diseases due to increased air pollution and the frequency of dust storms. The

number of malignancies gradually increased during the study period. For example, in 2021, this figure was 158.3 cases per 100,000 population. The overall incidence of the population increased to a record 139,521.0 cases in 2021, indicating a complex deterioration in the health of the city's population in the face of climate change.

Using the data from table 1, the forecast values of the number of these diseases for the period 2023-2029 are determined. To achieve this, the trends in disease incidence over the study period were analyzed. Additionally, the previously provided data allow for a graphical representation of these trends over the years (Figure 1).

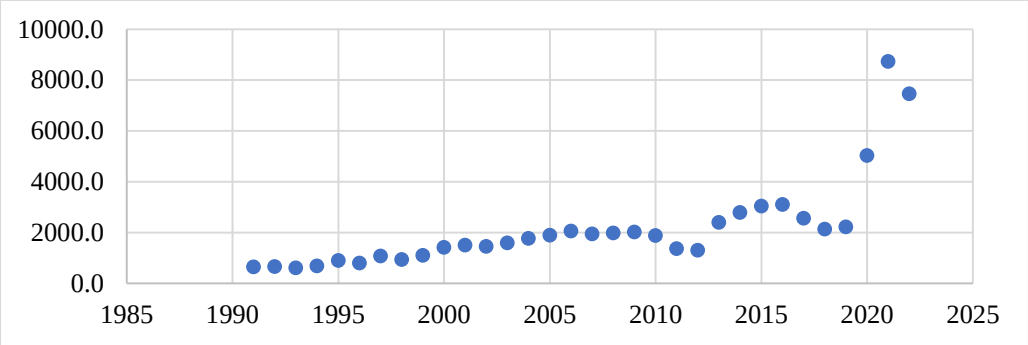


Figure 1: Morbidity of the population with diseases of the cardiovascular system

The graph shows a trend of increasing morbidity with peak values, which may indicate the influence of external factors, such as an increase in the average annual temperature. Individual anomalies in indicators may be related to socio-economic changes or medical interventions. Figure 2 illustrates the dynamics of the population's incidence of respiratory diseases over the same period.

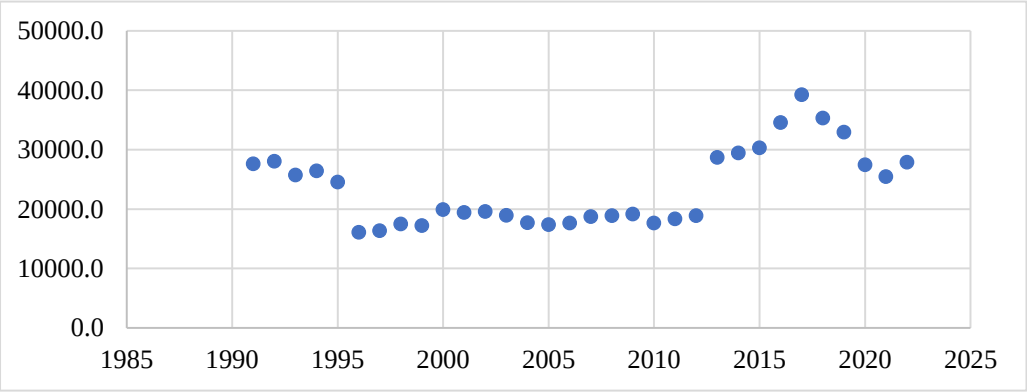


Figure 2: Morbidity of the population with respiratory diseases

The graph shows fluctuations in indicators, in particular, an increase in morbidity during periods with high temperatures or in conditions of drought, which may be associated with a deterioration in air quality. Sharp peaks are observed, especially in years with abnormally high temperatures, which indicates an increase in cases of allergic reactions and respiratory infections. Figure 3 shows trends in the incidence of cancer in the population between 1991 and 2022.

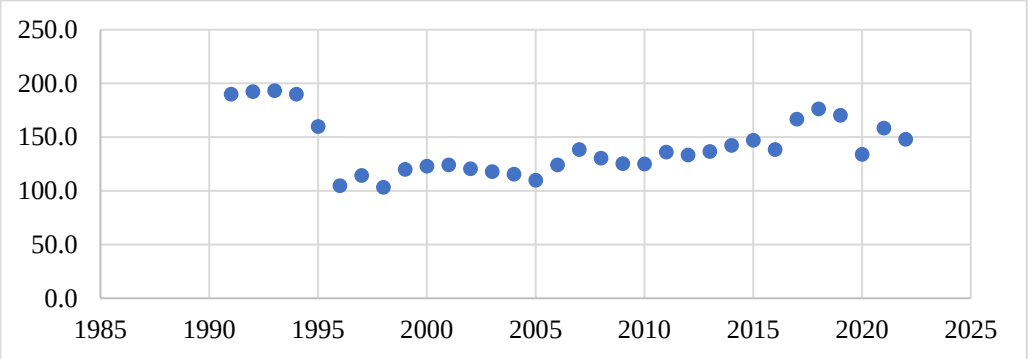


Figure 3: Incidence of cancer in the population

The graph shows a gradual increase in cases, which may be due to a variety of factors, including environmental changes, eating habits, and genetic background. The increase in morbidity may also be associated with better availability of health services, increased public awareness, and, consequently, more frequent diagnosis of cancer. As a result, figure 4 illustrates the dynamics of overall morbidity in the population for the period from 1991 to 2022.

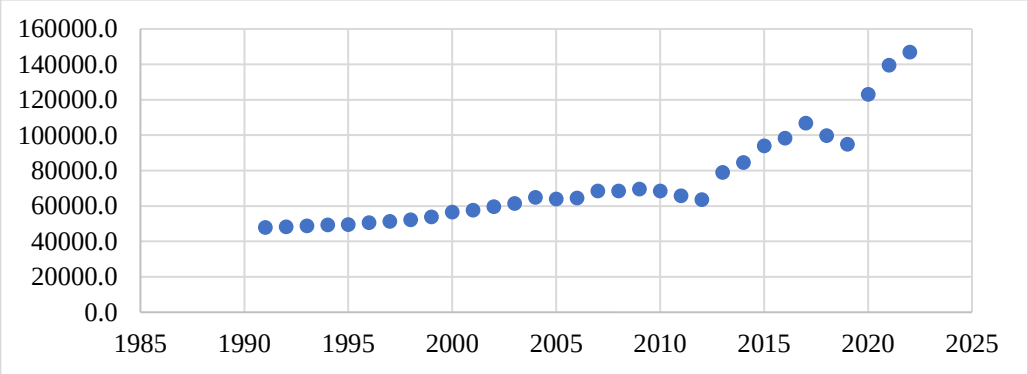
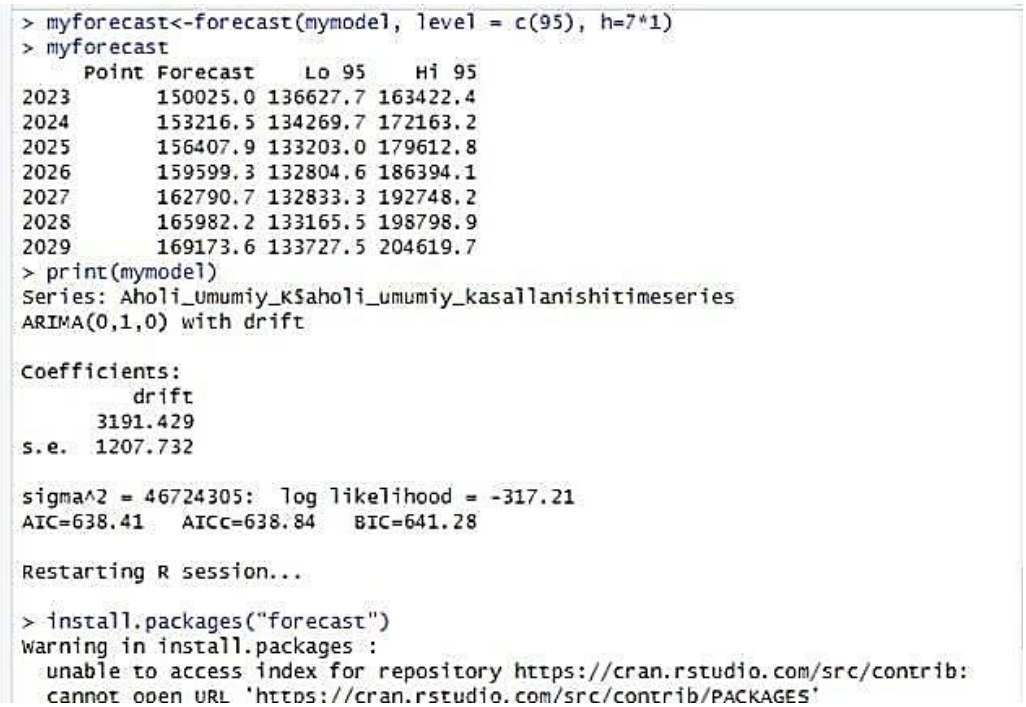


Figure 4: General morbidity of the population

The graph shows a general trend of increasing morbidity, reflecting not only an increase in cases of diseases but also a complication of the situation in the health system. The graph shows periods of substantial growth that may correlate with certain social, economic, or environmental changes, such as global warming, that affect the overall health of the population. The increase in morbidity among the population in the context of cardiovascular diseases is particularly pronounced, which underlines the importance of this category. The presented images show the dynamics of growth in the number of common diseases among the population and diseases of the circulatory system in particular. A time series model was used to analyse the data since changes in morbidity are non-linear. This means that simple linear models are not able to adequately reflect all the fluctuations and anomalies observed in the data, and using a time series model allows identifying hidden patterns and trends, and making more accurate forecasts for the future. R software was used to determine the best forecasting model (Figure 5).



```
> myforecast<-forecast(mymodel, level = c(95), h=7*1)
> myforecast
     Point Forecast    Lo 95    Hi 95
2023       150025.0 136627.7 163422.4
2024       153216.5 134269.7 172163.2
2025       156407.9 133203.0 179612.8
2026       159599.3 132804.6 186394.1
2027       162790.7 132833.3 192748.2
2028       165982.2 133165.5 198798.9
2029       169173.6 133727.5 204619.7
> print(mymodel)
Series: Aholi_Umumiy_K$aholi_umumiy_kasallanishitimeseries
ARIMA(0,1,0) with drift

Coefficients:
         drift
      3191.429
s.e.  1207.732

sigma^2 = 46724305:  log likelihood = -317.21
AIC=638.41   AICc=638.84   BIC=641.28

Restarting R session...

> install.packages("forecast")
Warning in install.packages :
  unable to access index for repository https://cran.rstudio.com/src/contrib:
  cannot open URL 'https://cran.rstudio.com/src/contrib/PACKAGES'
```

Figure 5: R software interface during data processing

Figure 5 shows the R software interface, where the best model was determined using the Akaike test. In this case, the ARIMA model (0, 1, 0) was chosen, which means that the model uses the same integration order, without autoregressive and moving average components. This indicates that there is a trend in the data without seasonal fluctuations, which is important for correct forecasting. Forecast data for 2023 indicate a substantial average incidence of 150,025 cases per 100,000 population. This indicator is an important indicator of the health status of the population, as it reflects the overall level of morbidity in society. The range of values varies from 136,627.7 to 163,422.4 and indicates some uncertainty in the forecast. This means that actual rates can fluctuate within this range, depending on many factors, including changes in environmental conditions, medical infrastructure, and socioeconomic factors.

The forecast for 2029 indicates a further increase in the overall incidence to 169,173.6 cases per 100,000 population. This growth is approximately 12.8% compared to the forecast for 2023. Again, the possible range of fluctuations is very wide, from 133,727.5 to 204,619.7. Such a large variation indicates that the situation can be very different depending on changes in the environment, the impact of new medical technologies, health policies, and public awareness of diseases. These forecasts highlight the importance of monitoring and responding promptly to potential public health threats. Considering possible fluctuations in forecasts also indicates the need to prepare the health system for various scenarios to reduce the risks and consequences of increased morbidity. The projected values of total morbidity in the population based on the ARIMA model (0, 1, 0) for the period from 2023 to 2029 are shown in table 5. The forecast includes 95% confidence limits, which indicate the probability that actual morbidity values will fall within this range with a 95% probability.

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Table 5: Predictive values of population morbidity determined using the ARIMA model (0, 1, 0)

Years	*95% lower limit*	*Predicted value*	*95% upper limit*
2023	136627.7	150025	163422.4
2024	134269.7	153216.5	172163.2
2025	133203	156407.9	179612.2
2026	132804.6	159599.3	186394.1
2027	132833.3	162790.7	192748.2
2028	133165.5	165982.2	198798.9
2029	133727.5	169173.6	204619.7

The lower and upper limits of 95% mean that the predicted values of the total morbidity of the population will take values in this given interval with a probability of 95%. Figure 6 graphically reflects the dynamics of morbidity of the population for the period from 1991 to 2023, in addition, it shows the projected dynamics for a further increase in the overall incidence for the period 2023-2029 – the upward line confirms the trend towards an increase in the number of diseases. The upper and lower limits of the forecast are indicated on the graph, visually reflecting the possible range of variations in the predicted values.

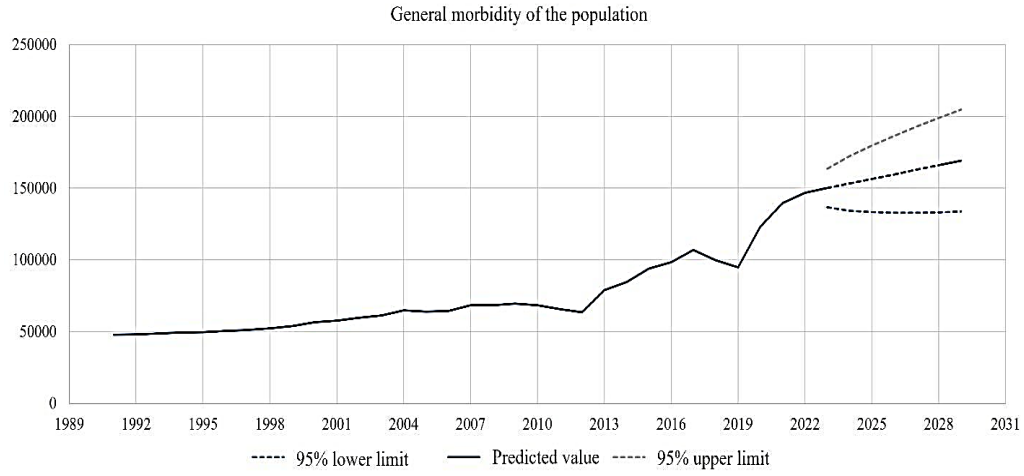

Figure 6: Dynamics and forecast values of the total morbidity of the population

Thus, the results of the study confirm the substantial impact of climate change on the health of the population of Tashkent. In particular, there is an increase in diseases of the cardiovascular system, which may be associated with an increase in average annual temperatures and deterioration of air quality. Climate change also affects the state of the respiratory system because the increase in the frequency of dust storms and air pollution negatively affects the respiratory health of residents.

Discussion

The results of the study show that an increase in average annual temperatures and deterioration of environmental conditions in Tashkent directly correlate with an increase

in diseases of the circulatory system, respiratory organs, and general morbidity of the population. This finding highlights the importance of the link between population health and climate change, which is a critical issue for the region, especially in the face of increasing climate extremes. Similar results were obtained in the study by Yurui *et al.* (2021), which focuses on the negative impact of rising temperatures and intensive use of natural resources on human health and ecosystems in China. Thus, issues of environmental restoration and adaptation to change become urgent for achieving sustainable development.

Analysing the dynamics of respiratory diseases, it was established that an increase in temperature contributes to an increase in environmental factors, such as dust storms, which negatively affect the state of the respiratory organs. This is consistent with the paper of Lam *et al.* (2020), who examined the impact of climate change on tropical fisheries. While their main focus was on food security and economic impacts, they also focused on how rising temperatures cause environmental conditions to worsen, which increases public health risks, including an increase in cases of respiratory diseases. An important aspect identified in the study is that climate change, combined with other environmental factors (such as air pollution and population growth), can lead to increased environmental and social problems. Similar conclusions were obtained by Salvia *et al.* (2019), who analysed trends in sustainability research and determined that climate change is one of the main obstacles that makes it impossible to achieve environmental sustainability. They note that adaptation strategies should include the integration of different sectors to ensure an effective response to climate change.

The results of the study, which confirm the link between rising temperatures and rising morbidity, highlight the importance of awareness of environmental threats in the context of public health. This correlates with the findings of Uralovich *et al.* (2023), who note that insufficient public awareness of climate change is one of the main obstacles to sustainable development. They focus on the need for environmental education and raising public awareness of environmental sustainability issues. Thus, the importance of environmental education and enlightenment, which the authors emphasise, can serve as a safeguard for reducing the risks associated with climate change. This, in turn, can contribute to the development of effective adaptation strategies that consider the needs of the population and environmental challenges. The availability of information on the impacts of climate change and its impact on public health can encourage active action on the part of the public and policy makers, which will generally have a positive impact on the sustainability of the region (Kovach *et al*., 2024).

The study also reviews disease projections for the period of 2023 to 2029, which were determined using the ARIMA model. The results predict a substantial deterioration in public health due to climate change. The projected increase in the number of diseases indicates the need to develop strategies for adapting and mitigating the effects of climate change (Krawczyńska *et al*., 2024). This aligns with the findings of Al-Shetwi (2022), which also emphasise the importance of introducing new technologies and innovations, especially in the field of renewable energy, helping reduce the effects of climate change by reducing air pollution, which, in turn, will help reduce the incidence of diseases.

The number of malignancies, as determined in the study, correlates with changes in temperature throughout the year in the direction of its growth, which emphasises the importance of environmental factors in the formation of long-term health risks. Shi *et al.* (2019) confirm this relationship, noting that climate change and rising pollution levels may influence cancer growth. The results of the study, which indicate an increase in diseases in Tashkent due to climate change, closely correlate with the results obtained by Blicharska *et al.* (2019). They stress the importance of preserving ecosystems and biodiversity as key factors affecting public health. The quality of life of the population, according to their data, directly depends on the state of the environment. Both studies focus on the critical role of ecosystem conservation in ensuring public health. Conclusions of Blicharska *et al.* (2019) on the impact of environmental health serve as a confirmation of the need for efforts to improve environmental quality to achieve overall well-being.

The main focus of this study was to identify the relationship between an increase in the incidence rate among the population and changes in the average annual temperature. This is essential for the development of environmental policies and strategies for adapting to climate change. In the context of the study by Katila *et al.* (2019), it is emphasised that sustainable development goals are closely related to environmental aspects, and environmental stability is crucial for maintaining public health. While the results of the current study focus on rising morbidity as a consequence of rising temperatures, a study by Katila *et al.* (2019) notes that global climate change can disrupt the balance between environmental sustainability and economic development. This is especially true for an urban environment such as Tashkent. Both studies highlight the need to integrate environmental aspects into health policy since environmental degradation directly affects public health.

The results of this study contrast with the analysis of Eisenmenger *et al.* (2020), who criticise modern approaches to sustainable development for mainly focusing on economic growth, neglecting the rational use of natural resources. In the case of Tashkent, the growing incidence of diseases underscores the need to review policy strategies to consider climate change and avoid further exacerbating environmental problems. Both approaches indicate that the conservation of Natural Resources is necessary to ensure public health. The results of the study also reflect the need to integrate environmental, energy, and water systems to ensure sustainable development, which is consistent with the findings of Baleta *et al.* (2019). The authors emphasise the importance of having an integrated approach to the use of natural resources, in particular, water, to reduce the negative impact on ecosystems in general and overall health in particular since the problem of preserving the health of the population directly depends on the provision of water resources and their uneven distribution, which confirms the need for an inter-sectoral approach to solving socio-environmental problems in the city of Tashkent.

In addition, the results obtained confirm the importance of developing sustainable tourism, as noted by Hall (2021). The rise in disease incidence due to increasing temperatures can negatively impact the region's tourism potential. Environmental deterioration and heightened health risks make tourist areas less attractive, potentially reducing visitor numbers (Trusova *et al.*, 2020). This explains the importance of

implementing environmental strategies in the tourism industry to support its development in the face of climate change. Polasky *et al.* (2019) consider the role of economics in environmental and sustainability analysis and argue that ignoring environmental impacts in favour of economic indicators can lead to substantial losses in the long run. The results support this claim by demonstrating how environmental degradation negatively impacts public health, ultimately leading to long-term economic losses.

Palomares *et al.* (2021) emphasise the importance of artificial intelligence in achieving sustainable development goals, pointing out its potential to improve environmental resource management and respond more effectively to climate change. While their study focuses on technological innovation, the results of the current study show that the growing incidence of diseases in Tashkent associated with climate change requires urgent implementation of adaptive strategies that include modern technologies. Both studies point to the need to create predictive models for planning actions that reduce the negative effects of climate change.

The results of the study, which showed that climate change and an increase in average annual temperatures correlate with an increase in morbidity among the population, have parallels with the results of Fan, Fang and Zhang (2019), who examine the relationship between the ecological state and the socio-economic development of megacities in China. It is determined that rapid economic development provokes degradation of the environmental situation in urban areas, which worsens the health status of the population. These findings highlight the need for a balanced approach to socio-economic development that takes into account environmental aspects.

The findings, which highlight the importance of integrating socio-environmental factors into population health analysis, are similar to the study by Scharpf *et al.* (2021). They considered socio-environmental factors that affect the mental health of refugee children and established that worsening environmental conditions can increase mental health risks in vulnerable populations. The results show a similar impact of environmental changes on physical health, in particular, due to an increase in the number of cardiovascular and respiratory diseases in the adult population. Behjat and Tarazkar (2021) also investigated factors affecting environmental well-being in Iran and determined that environmental pollution and poor use of resources are among the main causes of quality of life degradation. The results show similar trends in Tashkent, where air pollution, along with rising average annual temperatures, impairs public health.

Finally, Figueiredo and Chen (2021) emphasise the importance of an environmental perspective in healthcare. They argue that maintaining environmental conditions is critical to ensuring the well-being of the population, which is consistent with the findings that temperature changes and the deterioration of environmental conditions in the city of Tashkent negatively affect the incidence rate among the population. Overall, the results support the findings of many other studies that highlight the importance of sustainable development and maintaining ecological balance for residents' health. The study demonstrates that climate change can negatively affect the health of the population of urban areas such as Tashkent, which requires further research and the implementation of effective adaptation strategies.

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Conclusions

The study confirmed that the temperate climate and agricultural development of the region provide favourable conditions for the growth of the population of Tashkent. During the period from 1897 to 2023, the number of residents of the city increased elevenfold – from 154,400 people in 1897 to almost 3 million in 2023. This demographic surge has directly affected the ecological state of the city: the expansion of the area, increased resource consumption and the burden on infrastructure have led to noticeable environmental pressures that require new approaches to effective resource management. The industrialisation of the city, which provides 19.7% of Uzbekistan's production volumes, also affects the environment: the concentration of production contributes to an increase in air and water pollution. The spread of industrial facilities and the expansion of urban areas have led to the loss of green areas, deterioration of air quality and the emergence of new pollutants that directly affect public health.

The results of the study showed a substantial impact of climate change on the level of morbidity of its population. The use of the Spearman correlation coefficient allowed establishing that the average annual temperature plays an important role in changing morbidity rates, especially for diseases of the circulatory system, respiratory system, and cancer. When calculating the Spearman correlation coefficient to identify the relationship between average annual temperature and population morbidity, the value $p = 0.761$ was obtained, which on the Cheddock scale corresponds to a strong and direct relationship. This means that an increase in the average annual temperature is accompanied by an increase in the incidence of cardiovascular diseases among the population of Tashkent, which indicates the need to take adaptive measures to reduce the negative consequences of such changes.

In particular, an increase in the average annual temperature during the study period correlates with an increase in the number of cases per 100,000 population. This increase may be the result of poor air quality, prolonged exposure to high temperatures, and associated habitat changes that increase the population's vulnerability to cardiovascular and respiratory diseases. Forecast for the period 2023-2029, made using the ARIMA 0 model 1.0, indicates that the trend of increasing morbidity continues. It is expected that the number of cases of cardiovascular and respiratory diseases will continue to increase, increasing the burden on the medical system. In particular, according to the forecast, the overall incidence may reach 169,173.6 cases per 100,000 inhabitants by 2029. These forecasts highlight the need for immediate implementation of adaptation measures, in particular, improving medical and preventive services, and measures to reduce the harmful effects of climate change on health.

One of the limitations of the study is to focus only on the relationship between temperature and morbidity, without considering other potentially important factors, such as the socio-economic status of the population, the quality, and availability of Health Services, the level of air, water, and soil pollution, which can also affect the dynamics of morbidity. This creates prospects for further research, which should include a comprehensive analysis of climate and environmental changes in the context of social, economic, and health conditions. The priority of further research is to analyse the impact of climate change on specific groups of diseases, such as respiratory, cardiovascular, and

oncological; develop adaptive measures to reduce the negative impact of climate on health, especially in densely populated cities. Effectively addressing these challenges requires cooperation between environmentalists, medical professionals, the government, and international organisations. The creation of adaptation programs, which include prevention, early detection of diseases, development of medical infrastructure, and educational initiatives, will contribute to the formation of sustainable health systems and increase the adaptability of the population to change.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2	Author 3	Author 4	Author 5
Conceived and designed the research or analysis	No	Yes	No	Yes	Yes
Collected the data	Yes	No	Yes	No	Yes
Contributed to data analysis and interpretation	Yes	Yes	No	Yes	Yes
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